UNITED STATES DEPARTMENT OF AGRICULTURE

FOREST SERVICE

MOTOR GRADER TEST

Report of

Warco Grader - Model 4D-100

San Bernardino and Angeles National Forests

January 17 - February 8, 1951

by

Division of Engineering

and

Arcadia Equipment Development Center

Region 5 - Forest Service

U. S. Department of Agriculture

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TABLE OF CONTENTS

Subject Headings (Cont.) Page

Tables & Figures		Page

Tables and Figures (cont.) Page

ABSTRACT

This report covers the inspection and testing of the Heavy Class Warco Grader to check compliance with existing specification and to determine its ability to perform the ordinary maintenance and construction work encountered in Forest Service operations.

Inspection and test showed that the unit complied with all major requirements of the specifications. The Warco 4D 100 Grader was able to perform all of the required tests in a satisfactory manner.

Blade maneuverability and stability was equal to that of any of the other acceptable machines tested in 1950.

Operator reaction placed the Warco as being better than average and an easy machine to operate.

In general, workmanship was considered good with a slight tendency to skip over some of the final finish jobs after assembly of the unit.

INTRODUCTION

The grader test described in this report is the result of an effort on the part of the Division of Engineering to determine the adequacy of commercial units offered on bid invitation to perform in accordance with the rigid requirements of the field. This report is on one unit of the Motor Grader Test Project conducted on the San Bernardino National Forest, January 23 to March 15, 1950.

Originally scheduled for two units, the project was expanded at the request of manufacturers to include five companies and five graders ranging from the 22,000 lb. to the 27,000 lb. classes.

This is one of the individual reports prepared for each of the five graders tested. The results of the entire test project are summarized in a composite In-Service, Confidential report which includes a more general analysis and encompasses a wider scope in objectives.

The actual field testing of the graders was divided into two major sections (1) physical characteristics, and (2) field performance.

The first section, referred to as the "flat land" test, consists essentially of observations as to physical design characteristics. This includes such items as clearances, blade maneuverability, turning radius, observations on operational features, visibility, operation of controls, and other such data as would be apparent from a detailed inspection of the machine.

The second section consists of a series of field tests designed to simulate the various field operations normally encountered in routine truck trail maintenance on the National Forests. Such operations as bank sloping, drainage dip construction, three-pass road maintenance, finish grading and several others are included to establish the field operation characteristics of the grader tested.

Every effort has been made to assure comparable test conditions for all graders. Standard procedures were devised, quantities and distances measured, and particular attention paid to soil conditions. Operators were given an instruction period prior to test and allowed to use the machine until such time as they were considered competent by company representatives or, in their absence, road foremen skilled in the use of patrol graders. Company representatives were encouraged to request re-runs where they felt conditions adverse or their machine capable of better performance.

WARCO GRADER

The grader furnished for test was a Model 4 D 100 Warco, manufactured by the W. A. Riddell Corporation of Bucyrus, Ohio. The unit was rated as a heavy class tandem drive with leaning wheels and full revolving circle, was equipped with deluxe cab, scarifier, and had the same size tires on front and rear wheels. The controls were hydraulic; brakes were provided on all tandem wheels; and the grader was powered with an electric start, 100 hp. International Harvester Company Type UD 16 Diesel Engine.

Fig. 1. Warco Grader, Model 4 D 100

DESCRIPTION OF TESTS

Section 1

Flat Land Tests

The first phase of the "flat land" test was the obtaining of data covering weights, dimensions, clearances, engine data, fuel requirements, and the other facts concerning the machine as usually given on manufacturers' specification sheets. Data taken from specification sheets and from the inspections are tabulated for comparison and shown as columns 1 and 2 of Table 1, Test Results Section of the report. In most cases the data agreed with that of the manufacturer but in a few instances notable variations were obtained.

The second phase of the "flat Land" tests consisted of an appraisal of the other physical characteristics of the machine as applied to its various functions. The following tests were performed:

I. BLADE OPERATION

The purpose of this test was to determine the maneuverability of the blade and time required for movement from one position to another.

Equipment used consisted of protractor, tape, plumb bob, stop watch, straight edge, still and movie cameras.

The machine was set on a flat concrete slab. Three reference lines were established; one at the machine fore and aft center line; and one on each side of center, running from the inside of the front tires to the inside of the rear tires. All measurements taken were from these reference lines. Center position of the blade was established as that condition at which, with the blade touching the slab, the blade and circle were centered with the machine. Normal position of the blade was established as that position of the blade in which the machine could operate most advantageously with no change in lift arms or linkage. One cycle of blade circle operation was defined as 360° in the case of machines with full revolving blade, or in case of machines not full revolving the maximum degrees of turn of the blade between obstructions.

A. Operation of Circle. Measurements of time and angle of cycle were taken. Observations were made regarding possibility of damage to parts of the machine by operation of the blade.

B. Locking Devices. Observations regarding the presence or absence of circle locking devices, location, and whether or not they could be considered positive were recorded.

C. Bank Sloping Positions. Starting from centered and normal operating position, the blade was moved to maximum bank sloping angle without moldboard shift. Height of blade tip above ground, bank slope angle, position of heel of blade on ground with respect to the tire reference line, and time to shift to this position were recorded.

The moldboard was then shifted for maximum reach and the blade was set at $1\frac{1}{2}$:1, 1:1, 3/4:1, $\frac{1}{2}$:1 and 1/4:1 bank sloping positions. Height of tip of the blade above ground and position of heel of the blade with respect to the tire reference line were recorded. The time required to shift from blade centered, normal operating position to the maximum bank sloping angle was recorded. Still pictures of each bank slope position were taken.

D. Side Shift. The distance the blade could be moved to right and left of centered position, with and without manual moldboard shifting, was measured. The time required for each operation was also recorded. In all cases distances were measured with the cutting edge of the blade resting on the concrete slab. The crew to shift the moldboard manually was limited to the operator and one helper.

E. Blade Lift. With linkage set for normal operation position, measurements were made and time recorded for movement of the blade from ground level to maximum lift position, and also maximum depth below ground, using a pit for this purpose. The number of holes on lift links and the distance of possible adjustment was recorded.

Starting with blade and circle in center position and at right angles to center line of machine the maximum blade lift angle, both right and left, was measured. Links were adjusted as necessary but the blade was not rotated on the circle for this operation.

The height of the lowest point of the circle with the blade at ground level was measured.

F. Blade Reverse. Ability to reverse the blade was recorded. This test concicted of setting the blade at 45° for casting material to the right, then turning blade for backing up, so as to continue casting material in the same direction.

G. Pitch Positions. Information obtained on pitch positions was as follows - number of notches, total adjustment distances and the degrees from the vertical both plus (top ahead of bottom), and minus (top behind bottom.)

H. Visibility. With the blade centered and at 45°, in both right and left positions, visibility of blade and front wheels was appraised from still photos taken from normal sitting position showing view to right, left, and straight ahead. This procedure was repeated for visibility from a standing position.

Rear view visibility was also noted, with still pictures recording actual views.

II. WHEEL LEAN

The purpose of the test was to determine the degree to which the wheels could be leaned for turning and for resistance to side thrust in operation.

The degrees of lean, both left and right, were recorded, and still shots were taken showing angle as indicated by large protractor.

III. GRADER GROUND CLEARANCE

The purpose was to determine ability of the grader to clear windrows, rock and obstackes which might be encountered either in forward or reverse operation.

With wheels in a vertical position measurements were taken between lowest projections and the ground, behind the blade, and ahead of blade, the latter being limited to 8 inches on either side of center of the front axle. Particular attention was paid to the possibility of damage to steering geometry if it was the lowest projection.

With wheels at maximum lean, measurements were taken in the same manner.

IV. WIDTH OF FRONT TREAD

To determine tread width of graders equipped with oversize tires in front, measurements were taken from center to center of tires, at point of ground contact.

V. SERVICING REQUIREMENTS.

The object of these observations was to determine the time consumed and materials necessary in servicing the equipment.

The number of grease fittings needing daily and weekly service were counted, and time for each service was recorded by equipment service men. Also recorded was the personnel necessary to do a grease job, lubricants and fuel used and types recommended by the manufacturers.

VI. TIRES AND RIMS

To determine adequacy and safety of this equipment, data were recorded regarding ply, size, number, and manufacturer of tires; type of rim and rim association number. At the end of the test, cuts, breaks and wear were recorded, giving reasons when possible. Still pictures were taken to show condition of tires.

VII. TANK CAPACITY

The purpose of this test was to determine ability of the grader to operate for one 8-hour shift with out requiring additional fuel.

Information recorded included factory specification on consumption, factory specification on tank capacity, hourmeter check, amount of fuel supplied, and whether or not eight hours operation was obtained from a full tank.

VIII. REMOVAL OF WINDOWS, DOORS AND CAB

The object was to determine the case with which doors, windows (windshield) and cab could be removed.

The test consisted of determining if windows, doors and cab were designed for removal, and estimating the time necessary for each operation. The major portion of data were obtained from Forest Service shop personnel and manufacturers.

IX. LIGHTS

The purpose of this test was to determine the adequacy of lights for night operation and travel.

Intensity of the lights was measured by a Weston meter at a distance of three feet. The source of electricity; whether generator, battery or magneto, was recorded. The location of lights, provision for adjustment, and adequacy of protection were noted.

X. ENGINE STARTING

The purpose of these observations was to determine the ability of the engine to start under field conditions.

Time for at least four different starts was determined by a stop watch. Temperature, humidity, whether the engine was hot or cold, type of starting and factory recommended sequence were recorded.

XI. OPERATION OF CONTROLS

The purpose of this test was to determine the adequacy of grader controls.

Information obtained included accessibility, response, ability to vary speed of control action, operation of any two controls at one time, and ease of gear shifting.

XII. TURNING RADIUS

It was desired (1) to determine the minimum circle in which the grader could turn, both right and left, and the road width necessary to do so, and (2) to determine the ability of the grader to turn by backing around in confined areas.

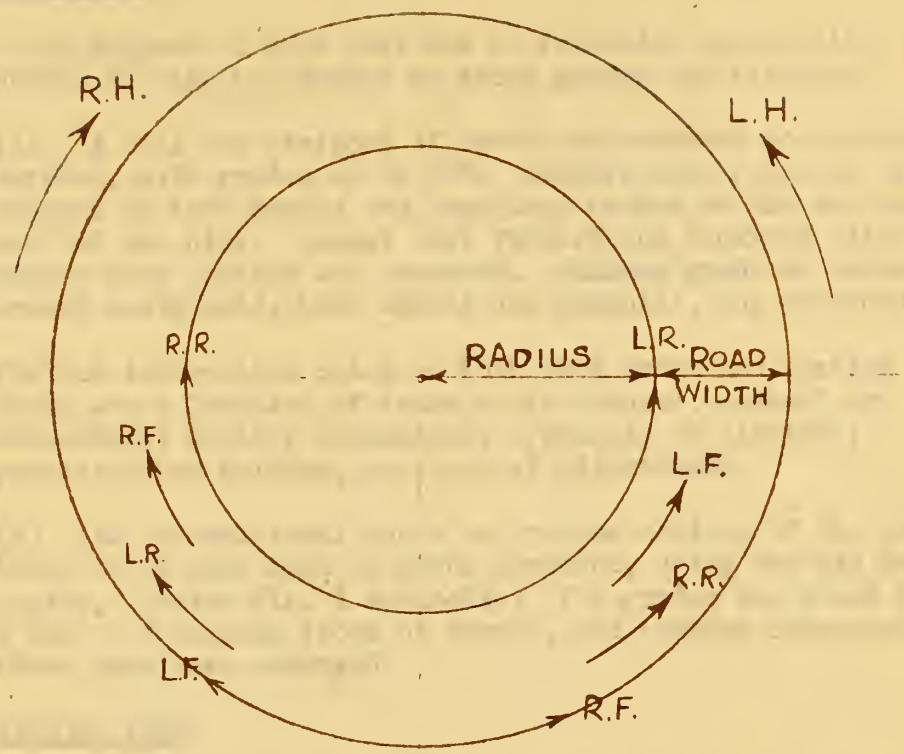
(1) The grader was turned to maximum, and driven to complete a 360° circle, in both right and left direction. The average diameter across the inside tracks was determined by a series of cross-diameter measurements from which the radii were computed.

A second set of measurements was taken across the tracks made in the turning process, and the average taken as the road width necessary for the minimum turn. (Refer to Fig. 2 for sketch.)

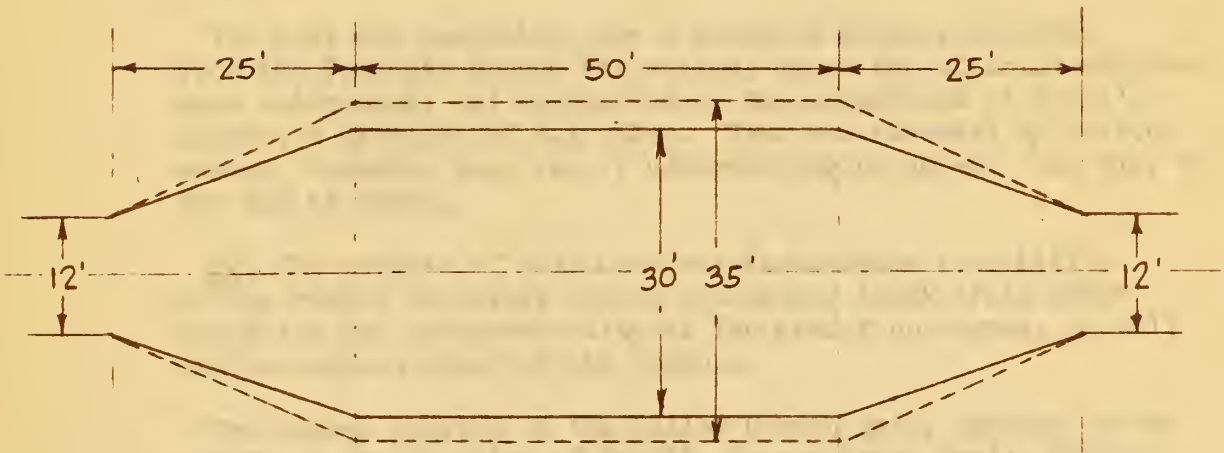
(2) A test area, simulating a turnout on a mountain road, was sketched on a paved area with chalk. The road width approach was 12 feet, tapering to 30 feet at a distance of 25 feet. The 30-foot section extended for a distance of 50 feet.

Operators were allowed to practice on the site so that only maneuverability of the machine was reflected in the test.

The object was to enter the area, turn around with the minimum number of backups, and drive out, keeping within perpendicular limits as designated by the sketched lines. A second set of lines was drawn with a 12-foot road and 35-foot turnout. Separate tests were conducted and results recorded for the 30-foot and the 35-foot width sections. (Refer to Fig. 2 for sketch.)

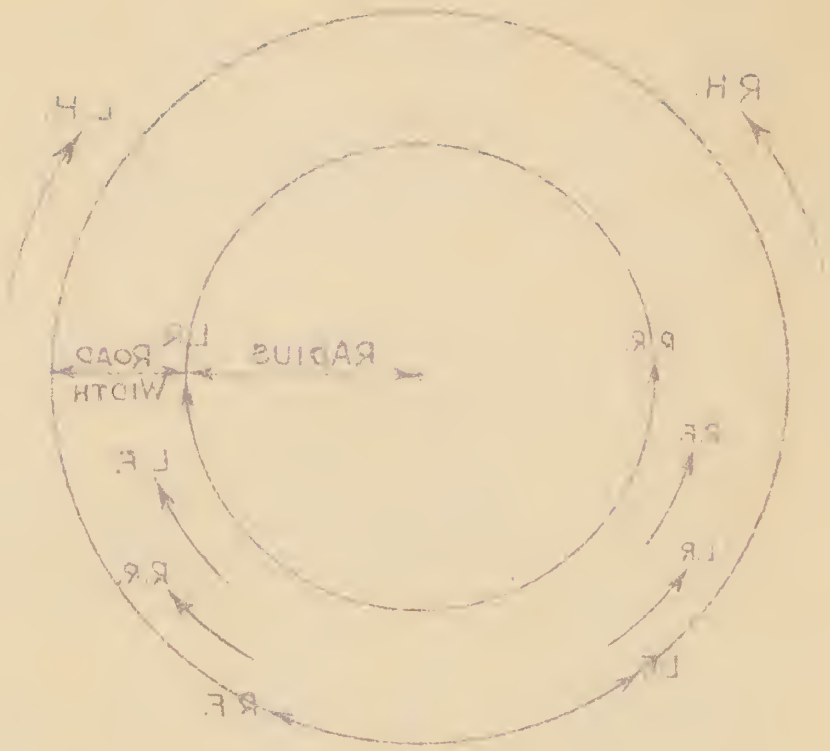


TURNING RADIUS TEST

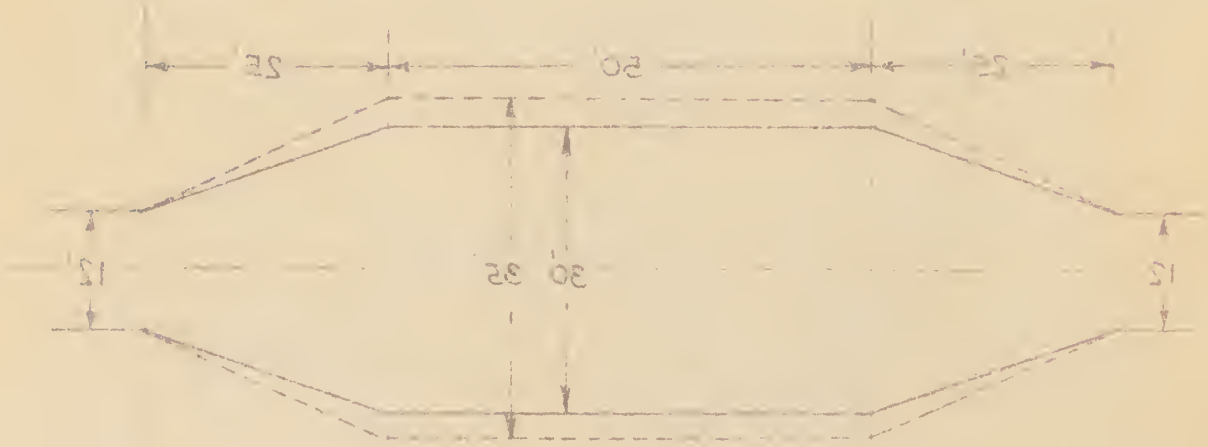


TURN AROUND TEST

FIG. 2



TURNING RADIUS TEST



TURN AROUND TEST

FIG. 2

XIII. BRAKE TEST

The purpose of this test was to determine the ability of the brakes to stop the grader on steep grades and highways.

(a) A hill was stripped of brush and prepared to a compact surface, with grades up to 49%. Graders were required to be stopped by foot brakes and emergency brakes on the steepest part of the hill. Actual roll forward and backward after brakes were applied was measured. Maximum grade on which brakes would hold, both uphill and downhill, was recorded.

Further information noted on both foot brake and parking brake was - location of drums as to 2-wheel, 4-wheel or driveshaft; whether mechanical, hydraulic or electric; provision for holding, and ease of adjustment.

(b) As an additional check on braking ability of the grader, brake tests were made on level pavement, using the AAA brake tester, (Refer Fig. 1 Appendix.) The grader was paced by a car to determine speed of travel, and braking distances for three runs were averaged.

XIV. WALKING TEST

This test was divided into two parts, the first conducted on a paved highway and the second on a truck trail.

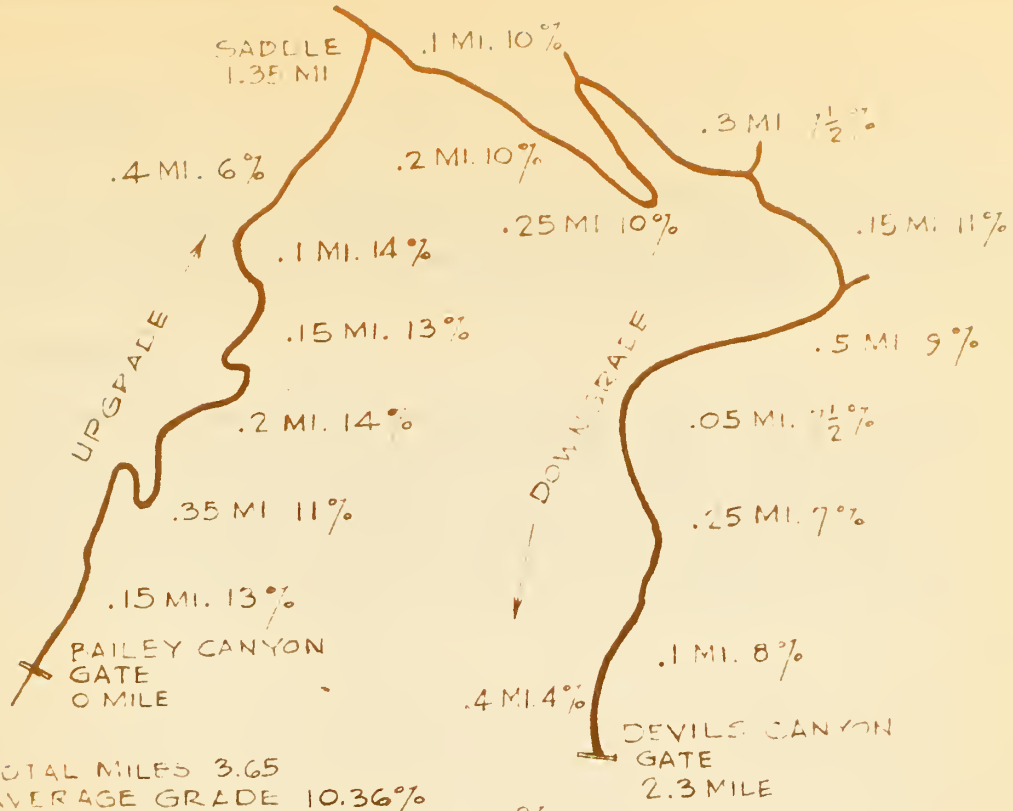
#1. The object in conducting this test was to determine the speed with which the grader could safely travel the highways.

The test was conducted over a measured course, starting from the Triangle Gravel Pit scales, where the official weights were determined, and terminated at the campground at Devil's Canyon, a distance of 6.1 miles. Time was recorded by a stop watch. Machines were run at governed engine speed. See Fig. 3 for map of route.

#2. The purpose of this test was to determine the ability of the grader to safely travel a measured truck trail which would tax the maneuverability of the grader on curves, as well as the maximum power of the engine.

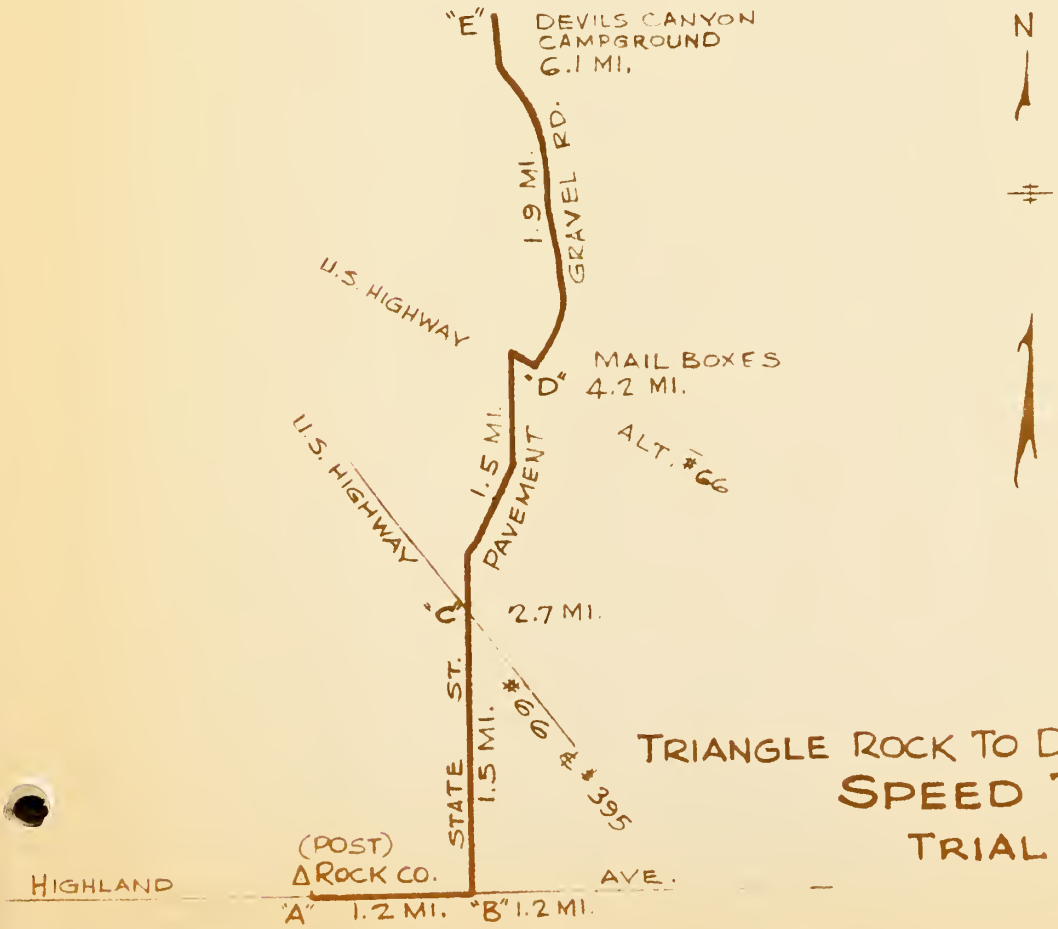
The course started at the Bailey Canyon gate, upgrade to the saddle at the junction of Devil's Canyon truck trail, thence downgrade to Devil's Canyon gate, a distance of 3.65 miles.

Data recorded were time for uphill and downhill trips, grades, and road condition. See Fig. 3 for map of route.



TOTAL MILES 3.65
AVERAGE GRADE 10.36%
1.35 MILES UPGRADE (AV. 11.83%
2.30 MILES DOWNGRADE (AV. 8.89%
CURVE LESS THAN 35' RADIUS

BAILEY CANYON WALKING TEST -TRIAL 2



TRIANGLE ROCK TO DEVILS CANYON
SPEED TEST
TRIAL 1

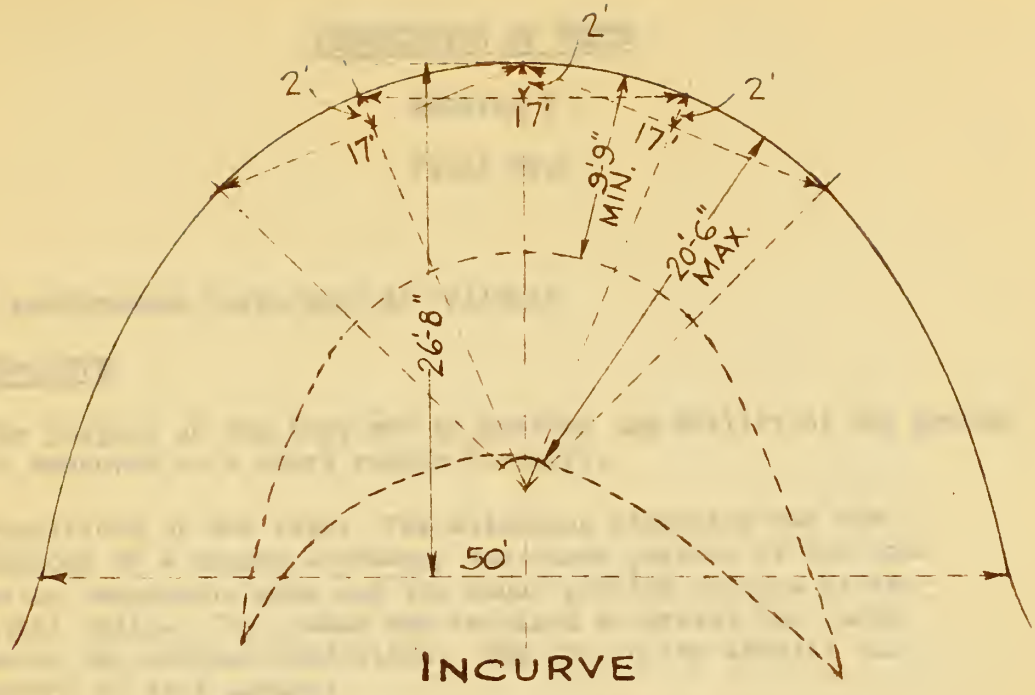
FIG. 3

XV. BREAKDOWNS

While not in the form of a test, an informational list was set up as follows: breakdowns, description of breakdowns, photographic record of each, cause (whether design weakness or accident), facilities to repair, availability of parts, and time lost.

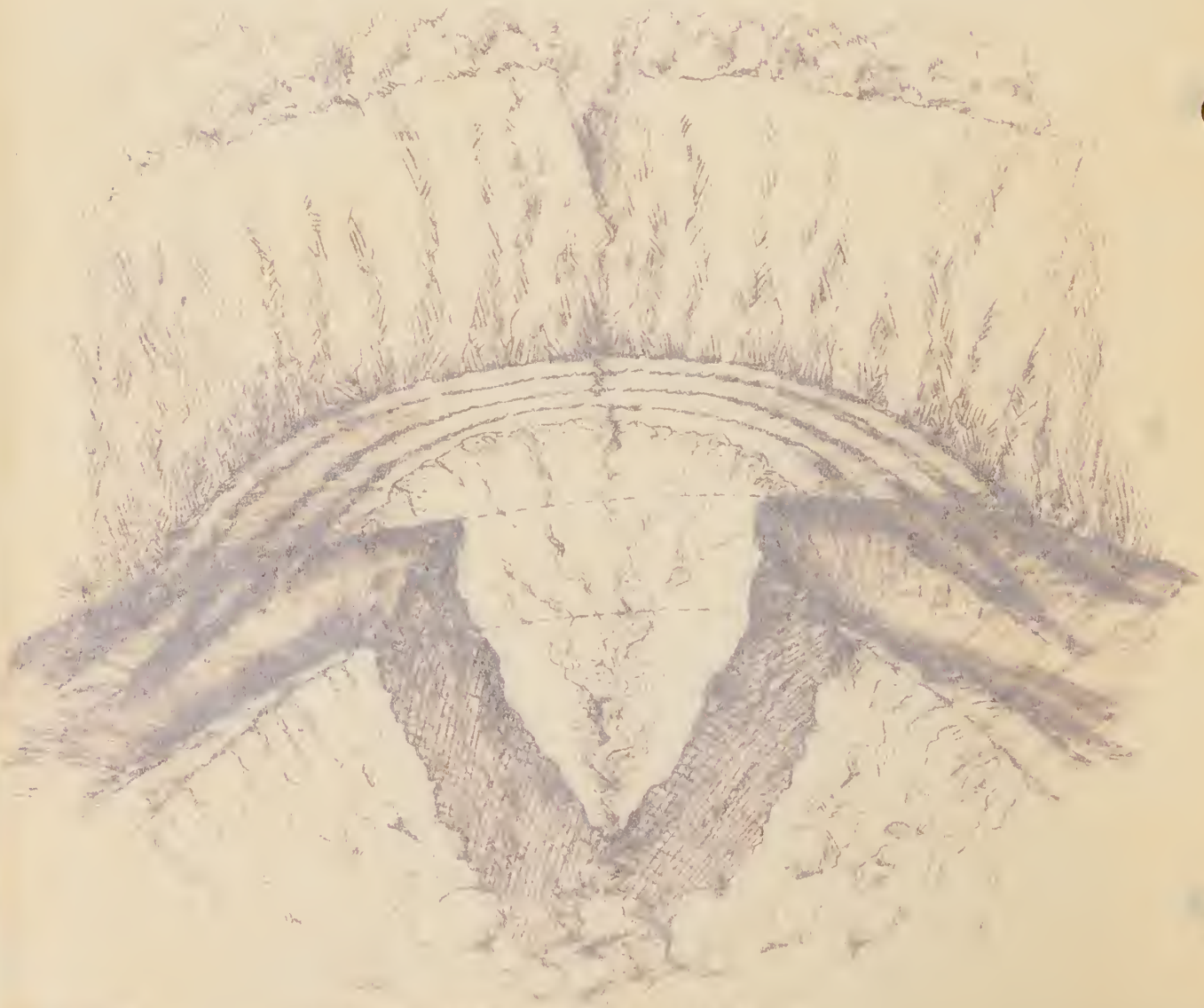
XVI. FINAL CHECK

After the grader had been put through the field tests of Section 2, it was returned to the "flat land" slab, thoroughly cleaned and carefully examined for all cracks, breaks and bends which were not evident as definite breakdowns. Each defect was described and photographed for permanent record. Pictures were taken of the tires to record wear and injuries.



SIMULATED CONDITION

FIG. 4



DESCRIPTION OF TESTS

Section 2

Field Test

Field performance tests were as follows:

I. IN-CURVE

The purpose of the test was to measure the ability of the grader to maneuver on a short radius in-curve.

Conditions of the test: The situation simulated was the washout of a canyon crossing, the outer portion of the road being completely gone and the inner portion defined by vertical walls. The grader was required to travel the curve, using the minimum road width. See Fig. 4 for details and sketch of test layout.

This condition results frequently after severe storms in rugged country. Ability of a particular machine to handle these situations would save much expense in importing a bulldozer for the operation.

Performance was recorded by use of movies and still pictures. The maximum width of road needed as measured from the inside tire track to the simulated perpendicular wall was recorded.

Since ability of operator affects the time required, re-runs were allowed if operator thought he could improve the performance. Regardless of time consumed, operator ability was evaluated in an attempt to determine machine performance, analyzing reasons for such.

II. GRADING OF DIPS

The life and usability of a road depends to a considerable extent upon the proper functioning of the drainage system. Grading of dips is one of the most important operations of a grader on roads where intercepting drainage dips are used.

The construction and maintenance of dips involves several of the functioning parts of a motor patrol. A dip consists of an involute curve, descending on an increasing vertical curve with an increasing outslope, until the depression is reached. The bottom of this depression is placed at an angle of 45 degrees to the center line of the road. The profile then rises rapidly for a distance of 15 feet to a summit, also at an angle of 45 degrees to the road center line, then returns to the normal road profile in a second distance of 15 feet. Refer to Fig. 5 for sketch.

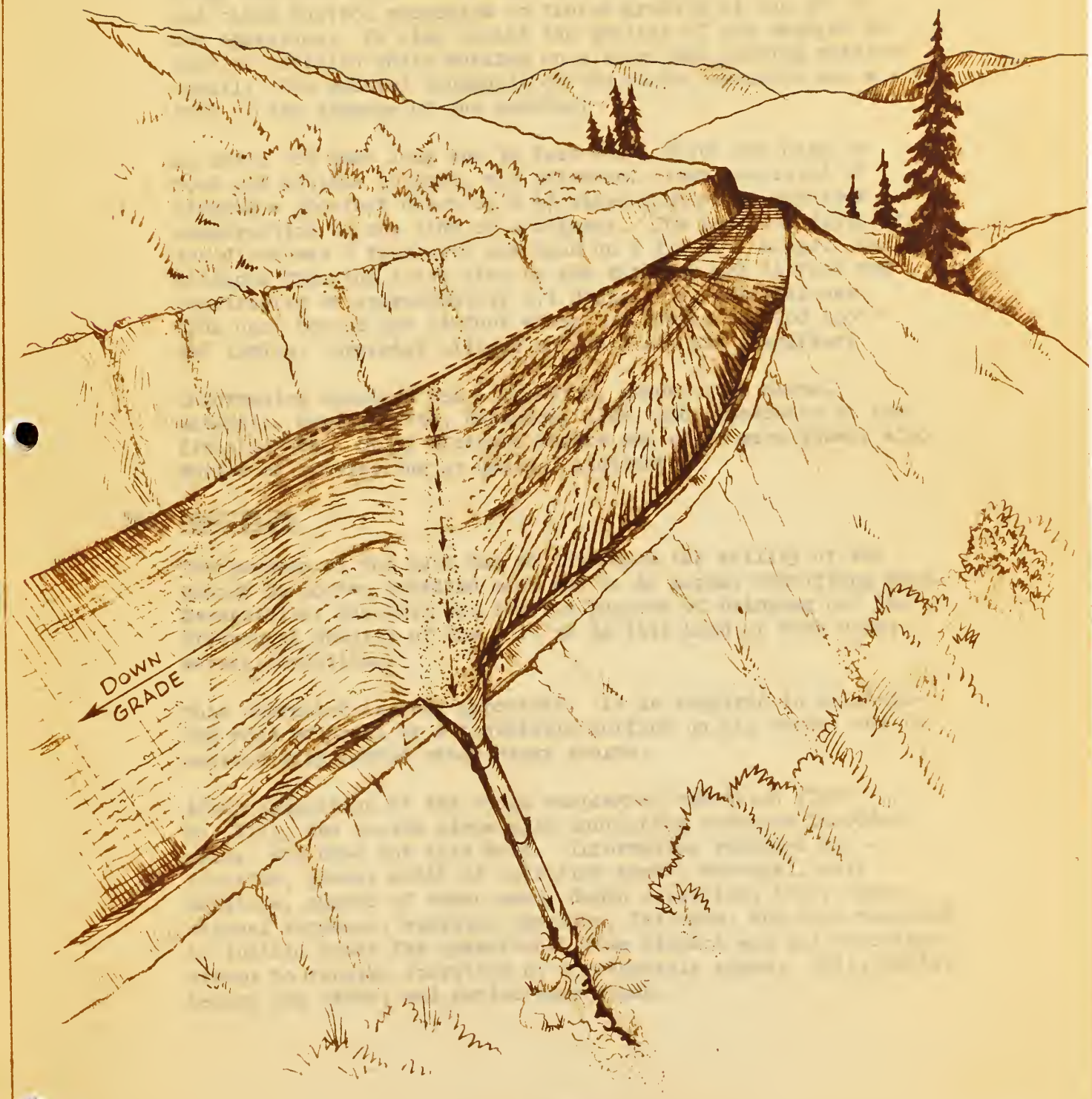
To construct or maintain a dip requires blade manipulation both above and below the plane of the base of the grader wheels. It also requires blade manipulation in a vertical plane to take care of the increasing outslope and also in a horizontal plane to take care of the changing angle of the outslope. This second manipulation is usually handled by steering.

A. New construction. Conditions: Operator practiced with grader until he was familiar with operation of machine and also the technique of dip construction. Stakes were set indicating beginning of cut, bottom of dip on a 45° angle and termination of berm. Operator was allowed as many passes as was necessary to construct to the proper standard as required by road foreman, who was judging this test.

   Still pictures were taken at site before operation and after, and movies taken during operation for the purpose of analyzing maneuverability of the blade. Information recorded was location, material, difficulties, operational sequence, time, soil moisture and foreman's rating of completed job.

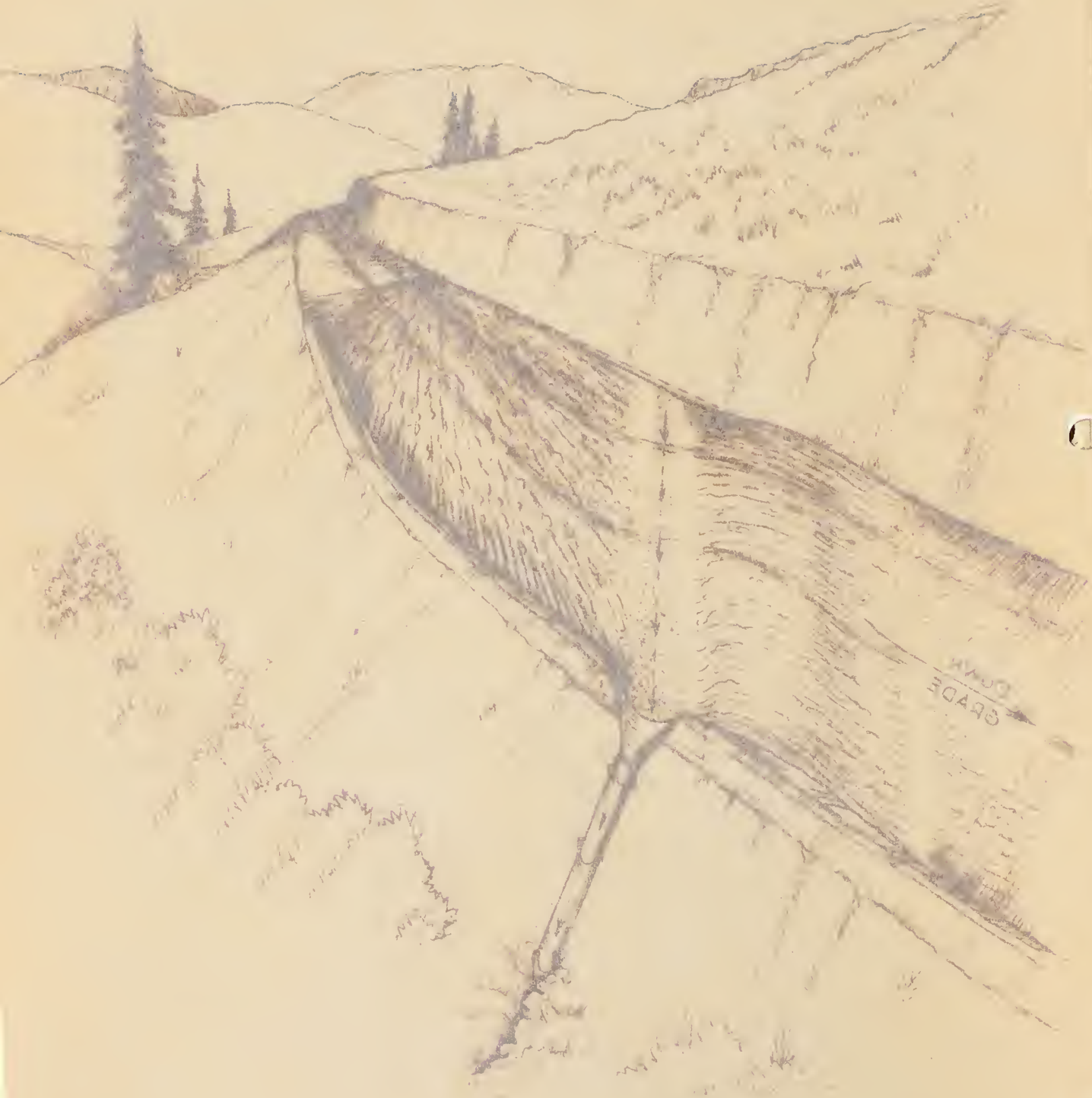
B. Maintenance of Dips. Existing dips were selected which were in need of reshaping and sluff removal. Motion pictures of operation were taken for analyzing blade response to controls and the ability of the blade to follow an existing profile. At the same time observations were made to determine if the lift mechanism range was adequate for below grade extension while possessing sufficient lift above grade to complete the operation.

   Still pictures before and after were taken. Location, grade, road width, material, difficulties and reasons, operational sequence, time, soil moisture, blade response and control were recorded.



INTERCEPTING DIP

FIG. 5



INTERCEPTING DIP

III. DITCHING

The purpose of this test was to determine the ability of the machine to function under difficult conditions involving extremely heavy work. The operation involved the use of the blade and scarifier in cutting dirt and rock and in removing large boulders by undercutting and pushing, and the blade and blade control mechanism in finish grading at the end of the operation. It also tested the ability of the machine to provide traction while working on a slope and pushing material uphill. The general toughness of the whole operation was a test of the stamina of the machine.

An area, 200 feet long and 32 feet wide, which was high in rock and boulder content, was selected. Test consisted of digging a 200-foot ditch on a 6% slope similar to shoulder construction on one side of a highway. The vertical depth of the ditch was 3 feet with cut bank on a 3/4-to-1 slope. The distance from the ditch line to the shoulder was 16 feet and constructed on approximately 4:1 slope. All material was side cast beyond the 16 foot width, or beyond the 200 foot end limits. Operator allowed to use blade and scarifier.

Information obtained was - location, grade, side slope, material, depth, width, distance, time, and appearance of the finished job. Still pictures before and after were taken, also movies of interesting or unusual incidents.

IV. SCARIFYING

The purpose of the test was to determine the ability of the grader to loosen imbedded rock and to do normal scarifying work. Essentially, the test was for the purpose of bringing out the structural ability of the unit to do this kind of work under severe conditions.

This operation is very important. It is required in maintaining road material or a travelable surface on all roads, and is particularly needed after heavy storms.

After completion of the rough shaping of the ditch (Test No. III), the inside slope area containing numerous imbedded rocks, was used for this test. Information recorded was - location, grade, width of scarifier swath, material, soil moisture, number of teeth used, depth scarified, time, operational sequence, operator reaction, failures, and time required to install teeth for operation. Time element was not important except to require operation at a reasonable speed. Still shots, before and after, and movies were taken.

V. BANK SLOPING

The purpose of this test was to determine the ability of the graders to side-slope banks at any required slope from $1\frac{1}{2}$-to-1 to 1/4-to-1.

This operation involved the use and adjustment of the control arms, the use of the circle, and general manipulation of the circle and arms assembly.

Sections of roads 500 feet long were selected in which banks at least 10 feet high existed, and included in-curves, out-curves and tangents.

Information recorded was - location, grade, material, distance, time, maximum height of cut, analysis of finished job, difficulties, and operator reaction. Still shots were taken of grader in position, and of road before, during, and after. Short movie sequences were taken to record the operation.

Bank sloping on Forest Service work is done largely on reconstruction or heavy maintenance work. Although it does not involve a very high percentage of total volume, the occasions of use require a highly maneuverable blade assembly.

VI. HILL CLIMB

The purpose of the test was to determine the ability of the machine to climb grades up to 50% in both forward and reverse gears.

The site selected for the test had a runway with an overall length of 300 feet, which started level and gradually sloped up to a maximum of 49%. Grader was required to climb uphill forward and uphill backward, recording percent of grade at the forward point of stalling, if any. The decomposed granite surface of the hill was prepared before each run so no loose material hindered the test.

VII. UPHILL GRADING

The purpose was to determine the ability of the machine to climb uphill and do normal grading at the same time.

Road sections, 500 feet long, in which grades from 10 to 21% existed, were selected. One pass uphill was made.

Information noted was - location, material, soil moisture, grade, time, tendency of machine to drift under load, and appraisal by road foreman as to effectiveness of the work. Still shots before and after, and movies during operation were taken.

VIII. ROAD MAINTENANCE - LONG SECTION

The purpose of this test was to determine the overall ability of the grader to do all of the important functions of a road maintenance job. These operations include slide and sluff removal, dip maintenance, normal and fine grading, berm construction, and drifting. Bank sloping was not included. Operation was up and down hill and around minimum radius curves (under 35 feet), and involved the use of all grader controls.

This work is the primary purpose for which motor patrols are purchased and constitutes the larger portion of their use.

A section of truck trail with grades up to 20% and needing maintenance work, two miles in length, was marked by means of flags. Picture stations were marked for the purpose of before and after photographic records which would depict the different functions common to the operations of rock removal, sluff removal, dip cleaning and shaping, and fine grading. Three passes were required.

Information recorded was - location, material, distance, time, amount of work to do in rock, sluff removal, number of dips to shape, and number of minimum curves.

Appearance of finished job was appraised by engineers and road foremen.

Fine Grading

On the two mile maintenance section an area suitable for fine grading was selected where no appreciable amount of rock was present.

Results of the operation were carefully analyzed for absolute control of the blade, since this test was considered as a measure of the ability of the grader to handle surfacing operations.

Still pictures before and after were taken to indicate the degree of improvement resulting from the operation.

TEST RESULTS AND COMPARATIVE DATA

To facilitate comparison and to conveniently tabulate the various data obtained from the test, Table I, Comparative Data, has been prepared.

The data recorded in column (1) are taken from the manufacturer's published specification sheet, and cover the standard production model only.

In column (2) are summarized the data taken from the "flatland" and "field test" sections of the report. Discrepancies in this column from the manufacturer's ratings, as shown in column (1), may be attributed to definition or deviation from standard on the test machine. Where considered necessary, deviations are discussed under the Discussion of Test Results.

In column (3) and (4) are the data of other graders tested in this class. The intent here is to show the maximum and minimum of the other data collected. It should be noted that the maximum as shown does not necessarily infer the best; particularly, where time is involved. Careful appraisal of the item under consideration will be necessary to properly evaluate the tabulated results.

TABLE I

Comparative Data of Flatland Test

	Mfr. Spec. Req'mnts. (1)	Warco Tested (2)	Other Acceptable Graders Maximum (3)	Other Acceptable Graders Minimum (4)
WEIGHT				
Front Wheels	6,800	8,040	9,350	7,350
Rear Wheels	17,000	17,500	19,300	13,150
Blade Pressure	12,380	14,240	18,520	12,720
Scarifier Pressure	9,000	9,940	10,460	8,200
Total Wt.	23,800	25,480	27,950	22,560
DIMENSIONS				
Length Overall	25'-10"	25'-10"	25'-8"	24'-3"
Width Overall	95½"	95½"	94 3/4"	91 3/4"
Ht. Overall with cab	125"	125"	128"	116¼"
" " less "	110"	110"	104"	89"
Ht. inside cab	-	75 3/4"	75½"	69"
Wheel Base	19'-0"	19'-0"	18'-11"	18'-8"
Tread (Front) Cen. to Cen. Tires	80"	80"	83¼"	79"
Tread (Rear)	81"	81"	80"	78¾"
SPEEDS				
Min. Fwd. mph.	2.6	2.6	2.37	1.7
Max. " "	25.0	27.2	25.2	15.0
Min. Reverse	3.8	3.8	3.7	1.74
Max. "	5.3	5.3	6.13	4.1
Number Fwd.	8	8	8	6
Number Reverse	2	2	3	2
ENGINE				
Brake hp	100	100	104	76
No. cylinders	6	6	6	4
Rpm- Gov. Max. at full load	1800	1800	1990	1555
CAPACITIES				
Fuel Tank (Gal.)	53	53	60	54
Cooling system	20	20	20	6½
Crankcase (Qts)	18	18	23	16

TABLE I (Continued)

	Mfr. Spec. Req'mnts. (1)	Warco Tested (2)	Other Acceptable Graders Maximum (3)	Other Acceptable Graders Minimum (4)
TIRES				
Size, Front	14.00x24	14.00x24	14.00x24	13.00x24
Size, Rear	14.00x24	14.00x24	14.00x24	13.00x24
Ply		8	10	8
BLADE ASSEMBLY				
Moldboard-Lgth. Width, Thickness	12'x26"x3/4"	12'x26"x3/4"	13'x22½"x3/4	12'x22"x5/8"
Blade Side Shift (R&L) (Mfrs. Rating)	51"	52½"	69"	29"
Rt. Blade Side Shift from center Position (circle shift)	-	23½"	25¼"	19"
(Circle Shift & Link Adj.)	-	28½"	38¼"	19"
(Circle Links & Moldboard Adj.)	-	52½"	62½"	51"
Blade Lift Above Grd. Sect. 1 - Test E	18½"	18½"	16"	14 3/4"
Blade Lift below Grd. Sect. 1 - Test E	20"	19¼"	23½"	8¼"
Pitch Positions-number for tilting	6	3	13	6
Max. shoulder reach	72"	-	88¼"	75"
Bank Slope angle (Test conditions 1-0-3) (Wheel of blade on ref. line)	-	68°	74°	57½°
Circle Diameter	61"	61"	63"	54¼"
Degree turn blade W/scar. teeth	-	323°	320°	302°
" W/O Scar teeth	360°	360°	360°	320°
Lifting Speed (Approx)	1"-3"/sec.	1.85"/sec	2.37"/sec.	0.98"/sec.
SCARIFIER V-Type				
Weight	1350#	1350#	1475#	1300#
Swath Width	46"	46"	46"	46"
Teeth Number	11	11	11	9
Teeth Size	1"x3½"	1"x3½"	1½"x3½"	1"x3"
Pitch positions	3	3	5	1
Pressure Max.	9,000#	9,940#	10,460#	8,200#

TABLE I (Continued)

	Mfr. Spec. Req'mnts. (1)	Warco Tested (2)	Other Acceptable Graders Maximum (3)	Other Acceptable Graders Minimum (4)
WHEEL LEAN				
Max. L.	20°	17½°	21½°	19½°
Max. R	20°	17½°	22½°	20°
GROUND CLEARANCE				
Behind Blade (Wheels	-	16½"	13½"	11 3/8"
Front " Vert.	30"	27"	27½"	14"
Behind Blade (Wheels	-	16½"	13½"	11 3/8"
Front " Max. Lean)	-	24" (?)	27"	20 3/4"
TURNING				
Turning Radius - R (Inside Wheel)	-	27'-10"	27'-9"	21'-10"
" " - L	-	30'-6"	29'-3"	22'-9"
Turn. Radius - Av. Inside Wheel and Av.		29'-2"	28'-6"	22'-5"
Road Width	40'-00	40'-11¼"	41'-2½"	30'-6"
Road width to turn - R	-	11'-10"	13'-10"	8'-0"
" " " " - L	-	11'-8½"	13'-2½"	8'-2"
FIELD TESTS				
ROAD WIDTH FOR TURN NO. OF BACKUPS				
35 Foot Road	-	3	3	2
30 " "	-	5	7	3
Dip Construction (Time)	-	26M-47S.	27M-0S	14M-36S
Ditch " "	-	10H-02½M	10H-22M	8H-20M
INSIDE CURVE				
Road width needed - Av. L & R	-	20'-1½"	19'-11½"	9'-7½"
Road Maintenance (mph) (3 pass)	-	.52	0.635	9.48
Brake Test Stopping Distance @18mph	-	25'-6"	38	15

TABLE I (Continued)

	Mfr's. Spec. Req'mnts. (1)	Warco Tested (2)	Other Acceptable Graders Maximum (3)	Minimum (4)
WALKING TEST (1)				
Paved Highway 4.2mi.	-	21.61mph	24.6 mph	15.8 mph
Dirt " 1.9mi.	-	15.2 "	17.25 "	12.35 "
Total " 6.1mi.	-	19.05 "	19.94 "	14.50 "
WALKING TEST (2)				
Uphill T.T. 1.35mi.	-	6.57mph	6.66mph	4.49mph
Downhill " 2.3 mi.	-	10.26 "	16.24 "	9.13 "
Total " 3.65mi.	-	8.49 "	9.98 "	7.70 "

DISCUSSION OF RESULTS

Flatland Tests

WEIGHTS

The weight distribution was found to conform very closely to that of the other tandem graders. Table II-A below shows the maximum deviation from the other tandems to be less than 5%. Deviations in front wheel blade & scarifier weights were on the favorable side.

TABLE II-A

Weights

Weights	Test Results (lbs.)	Ave. Wt. Other Tandem Graders	Warco	Other Acceptable Tandem Graders
Total	25,480	25,810	100%	100%
Front	8,040	7,790	31.6	30.3
Rear	17,500	17,880	68.7	69.7
Scarifier	9,940	8,930	39.0	34.3
Blade	14,240	13,840	55.9	53.8

Accordingly, the weight distribution for the Warco grader is considered in conformance with standard practice.

The blade pressure of 14,240 lbs. was above the average for other tandems. It did not approach the blade pressure of 18,520 lbs. recorded as the maximum for other machines tested. In order to clarify the comparison, it must be pointed out, however, that the unit with the greatest blade pressure was not a tandem, and that in obtaining this high blade pressure, the weight available for tractive effort was reduced below possible operational use.

In obtaining blade pressure, no difficulty was experienced with inability of the hydraulic system to exert maximum pressure to the extent of lifting the front end off the ground.

Scarifier pressure was found to be approximately the average of the maximum and minimum of other machines. Based on weight, equivalent swath, and number of teeth, the scarifier was considered adequate. Teeth were bent but this was considered normal for the type of work performed.

Proper weight distribution of some graders was questioned during the field tests because of loss of traction and a tendency to drift sideways. After reviewing the weights of all tested graders, it was apparent that horsepower was a factor to be considered along with weight.

Accordingly an analysis of overall weight per horsepower and drive wheel weight per horsepower was made. The results for the Warco are tabulated in Table II-B together with the maximum and minimum for tandem machines tested during 1950.

TABLE II-B

Weight Horsepower Ratios

	Warco	Other Acceptable Tandems Maximum	Minimum
Overall Weight	25,480	27,950	24,500
Wt. on Drive Wheels	17,500	19,300	17,150
Engine HP	100	104	100
Lbs/Hp, (Total Wt)	255	280	236*
" " (Drive Wheel Wt)	175	193	165*

* Machine with minimum ratios was considered on the borderline and could be classed as an excessive drifter.

The Warco falls in second place in the Weight horsepower values. The machine rated first was considered definitely stable.

It is not the intent of this report to determine the ideal ratio, but merely to suggest that this weight ppwer relationship may play an important part in the performance of a grader.

DIMENSIONS

The Warco was two inches longer and approximately one inch wider than any of the other acceptable machines. Wheel base was one inch longer than the maximum. The height clearance of 75 3/4 inches within the cab was more than that of any other unit tested.

The sizes and weights of box sections and frame members of the unit appeared adequate, and in conformance with construction of equivalent graders. Only a complete stress analysis, which was felt to be outside the scope of these tests, would prove the above.

SPEEDS

The transmission had eight speeds forward and two reverse. Gear reduction was such as to provide adequate variation for most types of work with a governed low speed of 2.6 miles per hour and a maximum governed speed of 27.2 miles per hour. On a road run of 45 miles from Arcadia to the San Bernardino test site, the unit was able to maintain an average speed of 22½ miles per hour.

From experience on previous tests there was reason to question the adequacy of the low speed. Operator consensus definitely indicated a lower low gear speed at governed RPM to be desirable for operation on narrow crooked roads.

The comments here apply only to speed, and are not intended to cover the transmission as a mechanism for changing speeds. This is discussed elsewhere in the report.

ENGINE

The engine was an International Harvester Model UD16, 6-cylinder, four stroke cycle, diesel, with a bore of 4.4" and a stroke of 5.5". It had a rated displacement of 501.8 cu. in. and a rating of 100 horsepower at a governed speed of 1800 rpm. The cooling system had a capacity of 20 gal. and the crankcase had an oil capacity of 18 qts. Fuel recommended by the manufacturer was #3 diesel oil.

The engine was of the electric starting type, using a 12 volt system. After warming up on gasoline fuel, the unit was shifted over to straight diesel operation.

Torque curve as submitted by the manufacturer showed a maximum of 335 lb. ft. at 1100 rpm. The gradual rise shown of from 300 lb. ft. at 1800 rpm to the maximum at 1100 rpm is a desirable engine characteristic for grader service.

The Vickers van type hydraulic oil pump, Model V235 was direct driven from the transmission power take off and was set for an operating pressure of 1100 psi.

The air compressor furnished was an independent unit driven by an electric motor and rated for operation at a pressure of 75 psi. The location of the compressor under the engine, was not thought to be proper. Based on the low pressure tires furnished with the unit, the compressor was considered adequate for normal operation of the grader.

I. BLADE OPERATION

A. Operation of Circle. The circle of the Warco grader was constructed of 6x4x7/8 inch structural angle iron fabricated to a radius of 61". The circle turning gear was made up of six segments of flame cut steel spur gearing welded into place on the lower edge of the vertical flange of the circle angle.

The time for one cycle of operation of the blade was 49 seconds. This was comparable to the time required for other acceptable tandems, which ranged from 40 to 52 seconds. The figures given above are for mechanically controlled machines. When the time required for the other hydraulically controlled machine tested was considered (1 minute 50 seconds) the Warco could be rated as having fast blade circle operation.

The blade could not be turned under full load and it was the consensus of observers that blade turn was possible only under approximately $\frac{1}{4}$ load. Operator reaction indicated the Warco to be below par in this respect. However, operator technique overcame this disadvantage to a considerable extent. The tests of all graders showed conclusively that blade turning ability under power is not serious unless turning by dropping a corner of the blade is prevented by a positive locking device. It was felt that any change that would increase the ability to turn blade under load would be a definite advantage.

With the Scarifier block raised to the non-operable position, but with the teeth left in, it was possible to turn the blade through a 360° cycle without interference. With the scarifier in operating position, range of circle turn was 323°.

The ground to circle clearance ahead of the blade was 27-3/4 inches, while clearance behind blade was 27 inches. It was possible to rotate the blade without appreciable lift at the forward end or drop at the rear as the blade passed the center line of the machine.

B. Locking Devices. Blade circle was operated by a rotary hydraulic motor which was connected to a chain drive reduction of 2 to 1 in the drive gear box. This in turn operated a worm gear unit having a reduction of approximately 30 to 1. This reduction was sufficient to insure that motion could only be transmitted through the driving side and provided adequate locking of the circle. The blade showed no creep under the heaviest loads encountered.

C. Bank Sloping Positions. Starting from centered and normal operating position the blade was moved to maximum bank sloping angle without moldboard shift. Height of blade tip above ground, bank slope angle, position of heel of blade on ground with respect to the tire reference line, and time to shift to this position were recorded. All above operations were done from the cab, with no manual adjustments required. The time required for shifting to maximum right or left bank sloping positions with blade centered on circle was three minutes.

The tabulation, Table III, shows the height of the tip of blade above ground for various bank sloping positions, together with maximum and minimum of the same measurements for other acceptable machines tested. Any angles above 30°, when the heel of the blade was not more than 8 inches outside the inside tire reference line, were considered inoperable.

To bank slope with heel of blade less than 8 inches outside would require that the wheels on the slope side be driven on the bank. This is particularly true for slopes above 45°. For this reason data showing blade measurements are given with reference to a line which was drawn from the outside edge of front and rear tires. Measurements given in the table are with the moldboard shifted on the moldboard arms.

TABLE III

Bank Slope Blade Positions

Note: Positions for Warco measured in reference to two lines, one at inside of wheels, the other at outside of wheels. All other graders measured from inside reference line only.

Bankslope	Angle	Measurement in inches	Warco Reference Line at Outside of wheels	Warco Reference Line at Inside of wheels	Other Graders Reference Line Inside Tires Maximum	Other Graders Reference Line Inside Tires Minimum
1½:1	34°	Ht. of tip above grd.	no	58	51	32
		" " heel " "	-	0	0	0
1:1	45°	Ht. of tip above grd.	69	82½	81	49
		" " heel " "	0	0	0	0
3/4:1	53°	Ht. of tip above grd.	93	113	112	82½
		" " heel " "	0	0	0	0
		Dist. heel outside ref. line	on line	on line	6	on line
½:1	63°	*Max. angle-Heel on ref. line	-	Max. 61°		
		Ht. of tip above grd.	126½	127	123	106
		" " heel " "	0	0	0	0
		Dist. heel outside ref. line	on line	on line	15½	3¼
¼:1	76°	Ht. of tip above grd.	Max. 70° 135½	145	138½	76½
		" " heel " "	-	2 3/4	0	0
		Dist. heel outside ref. line	7	12	23 3/4	12 3/4

*Note: Only in Warco test was this maximum angle determined with blade on inside reference line. All graders obtained 63° and distance outside the reference line was measured.

Figure 6 shows blade set for a 3/4 to 1 bank sloping position. Figure 7 shows the completed bank slope job for 3/4 to 1 before final pass was made to clear up the road bed.

Fig. 6. 3/4 to 1 Blade Position

Fig. 7. 3/4 to 1 Bank sloping

D. Side Shift. With the blade set at the center normal operating position, it was shifted 23½" to the right and 29" to the left by manipulation from cab controls only. No manual adjustment of drag link to shift from right hand to left hand operation was required. An additional 24" both right and left was obtained by manually shifting the moldboard on the support arms. There is available a power shift piston and control unit to operate the moldboard. with this unit installed, the Warco would be one-man operated and completely cab controlled. The times required for right moldboard shift by power control, as well as the distnaces are given in Table IV, in comparison with that of other machines.

TABLE IV

Blade Side Shift

With Blade Centered on Circle	Mfr. Spec.	Warco	Other Acceptable Machines Maximum	Minimum
Dist. Right	-	23½"	25¼"	19"
In. per sec. Shift	-	1.12"	.98"	.76"

The time required for the manual shifting of the moldboard on the support arms averaged 14 minutes 12 seconds for 5 individual changes. This was greater than the average of 9 minutes 9 seconds for other machines having the same type of moldboard shift, but was considerably less than the average time required for machines having the slide type of blade shifting mechanism.

E. Blade Lift. The maximum blade lift above ground, maximum drop below ground, angle of lift right and left with blade centered, and the clearance between blade cutting edge and bottom of circle are given in the comparison Table V.

TABLE V

Blade Lift

With Blade in Normal Operating Position	Mfr. Spec.	Warco	Other Acceptable Mach. Maximum	Minimum
Max. Lift Above Ground	18½"	18½"	16"	14-3/4"
Time for Max. Lift	-	10 Sec.	15 Sec.	6 3/4 Sec.
Rate of Lift (In/Sec)	1 to 3	1.85	2.37	0.98
Max. Drop Below Ground	20"	19¼"	23½"	8¼"
Clearance, Blade to Circle	-	27"	28¼"	25"
Max. Angle Rt.	-	22°	15½°	8°
" " Left	-	12°	12½°	8°

In the above group of operations, the Warco was definitely better than average. Blade lift, was $2\frac{1}{2}$" greater than for any other grader. It is significant that the maximums and minimums of the others represent four other units, and that the Warco is consistently above the average. These measurements were obtained by cab control only and did not necessitate manual change of linkage. All other tandems tested required manual linkage adjustment between maximum up and maximum down measurements.

F. Blade Reverse. With scarifier down, and teeth in operating position, the blade was rotated through a 323° angle. With scarifier tilted and held in non-operating position, blade was turned a full 360° with ample clearance and without interference or danger of damage to any part of the machine.

The time required to manually shift the scarifier block from operating to non-operating position was approximately four minutes. This is generally less than the time required to remove or reinstall scarifier teeth in other tandem machines.

G. Pitch Position. The comparative table of pitch positions and angle of pitch is given in Table VI.

TABLE VI

Blade Pitch

	Mfr. Spec.	Warco	Other Acceptable Mach. Maximum	Other Acceptable Mach. Minimum
Pitch Forward	-	$+46^{\circ}$	$+43\frac{1}{2}^{\circ}$	$+27\frac{1}{2}^{\circ}$
Pitch Rear	-	$+5^{\circ}$	-17°	$+9^{\circ}$
Pitch Positions	6	3	13	6

The angle of blade pitch compared favorably with other machines. The unit had only three pitch positions, which is less than that of any machine tested. No tests have been made to determine the adequacy of blade pitch positions for the Warco, or for other graders. It was observed that, for normal operation, dry material rolled off the blade readily.

It was the opinion of operators and observers that under some conditions better blade operation might be had if the top of the blade could be tilted further to the rear of the grader. In an attempt to do this, it was found that at an angle of $+1\frac{1}{2}^{\circ}$, see Figure 8, the blade hit against the drawbar where shown in Figure 9.

Possibly redesign of the drawbar at the point of contact with the top of the moldboard should be considered.

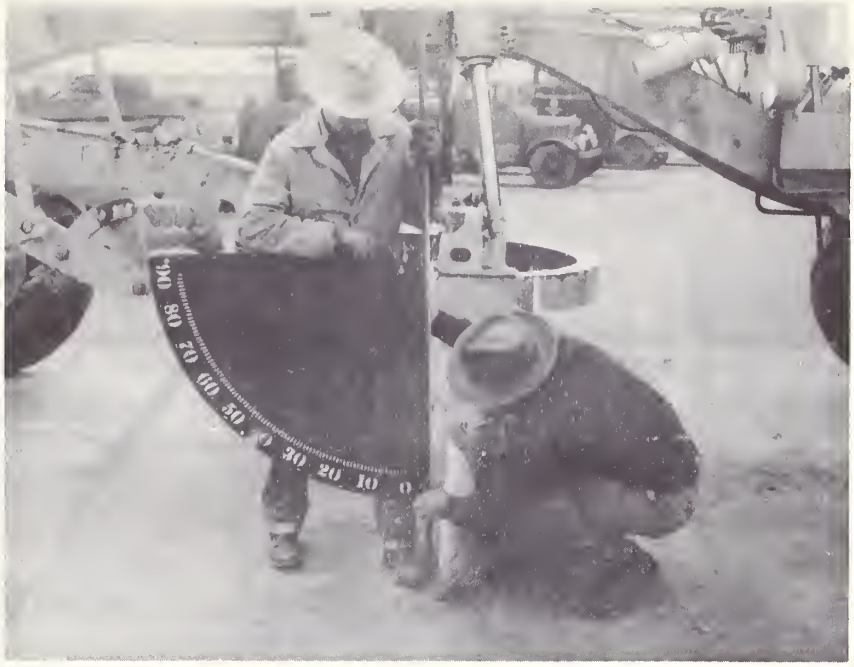


Fig. 8. $\downarrow 1\frac{1}{2}^{\circ}$ Pitch Position

Fig. 9. Blade Contact at Drawbar

H. Visibility. Visibility forward and to either side was better than the average of other machines tested for both standing and sitting positions.

Operators, however, expressed the opinion that, due to the height of the cab and position of the blade, it was difficult to judge the vertical location of the blade.

II. WHEEL LEAN

Angle measurements of wheel lean, as required in purchase specifications, as well as the maximum and minimum for other acceptable machines tested, are shown in Table VII.

TABLE VII.

Wheel Lean

	Left	Right
Specification Requirements	20°	20°
Warco	$17\frac{1}{2}^{\circ}$	$17\frac{1}{2}^{\circ}$
Maximum Other	$21\frac{1}{2}^{\circ}$	$22\frac{1}{2}^{\circ}$
Minimum Other	$19\frac{1}{2}^{\circ}$	20°

The wheel lean was less than specification requirements, as well as below that of any other acceptable machine tested. Because of this condition particular attention was paid to side shifting of the machine under heavy loadings, especially in the ditching operation. The machine was not considered as stable as two of the other machines, but was considered acceptable. It is the consensus of observers, however, that the wheel lean of the Warco is at the minimum that could be considered as effective for normal operation. Any decrease of the front end weight, without increase of the angle of wheel lean, would possibly be detrimental to normal operation. An analysis of the construction indicates that, with slight alteration, it would be possible to obtain an increase in wheel lean.

Opinions of the three operators who handled the machine during the tests revealed that they had no difficulty that could be attributed to deficiency of wheel lean. Figure 10 shows the maximum wheel lean of the Warco grader.

Fig. 10. Maximum Wheel Lean

III. GROUND CLEARANCE

Ground Clearance for the Warco grader, as compared with other machines, is given in Table VIII.

TABLE VIII

Ground Clearance

	Mfrs Spec.	Warco	Other Machines tested Maximum	Minimum
Wheels Vert.-Behind Blade	-	16½"	13½"	11-3/8"
" " -Front "	30"	27½"	27½"	22"

The clearance behind the blade was three inches greater than that of any other tandem tested. This increased clearance was due to the type of construction of the tandem housing which allowed for greater ground clearance of the transmission case. The increased clearance resulted in a higher center of gravity of the unit, and particular attention was given to possibility of instability. The ditching operation was the

one on which the unit operated at the greatest side slope. However, for this operation it was the consensus of observers that no difficulties were evident.

IV. FRONT AXLE TREAD

Test data are shown in Table IX.

TABLE IX

Front Axle Tread

Spec. Requirements	Warco	Other Graders Tested Maximum	Minimum
80"	80"	83¼"	79"

The tread was on the low and desirable side of the average for other units tested. Operation of the unit showed it to be acceptable in turning radius, turn around ability, and in other maneuverability tests.

V. SERVICING REQUIREMENTS

The total number of service points and the number requiring daily, weekly and monthly checks, are given in Table X.

TABLE X

Service Data

	Warco	Grader A	Grader B	Grader C	Grader D
Total Serv. Pts.	90	112	103	114	70
No. Daily Service	68	4	46	63	40
No. Weekly Service	5	77 (20 hrs)	34	50	9
Other	17	31	23	1	21
Total Points to Service Weekly	345	174	264	365	209

The data in the above table is not exactly in accordance with manufacturer's recommendations. This is primarily because of the difficulty in determining the actual lube points from the instructions furnished, and also because of the use of other than daily and weekly service periods. It is of interest that grader A, with only four points of daily servicing, had many lubrication points of the same type and design as those on the Warco, but were felt by the manufacturer of Grader (A) to need service at 20 hour intervals.

The table indicates that the Warco grader was below average in the number of service points requiring lubrication. This was felt by observers to be due to design, in that moving parts requiring service were reduced to a minimum.

The average daily time required to start engine, check machines for mechanical looseness, lubricate, and prepare for operation during the period of the test was approximately 20 minutes.

VI. Tires & Rims

Tires, as furnished, were Firestone 14:00 x 24, 8 ply lowpressure nylon cord type. Final inspection on completion of test showed tires to be in very good condition. Figure 11 shows the worst cuts on any of the tires after the test period.

Fig. 11. Tire Condition

Notes taken from the field data for all graders are listed below for comparison.

Warco	- Wear "negligible", breaks "none".
Grader A	- Wear "negligible", breaks "none".
Grader B	- Wear "negligible", Breaks "no breaks".
Grader C	- Wear "very little wear", breaks "none, some rock cuts - not serious".
Grader D	- Wear "negligible", breaks "none" (one small cut ((sidewall)) R.R. Tandem)".
Other	- "Tires badly worn and cut"

Tires on the Warco were inflated to 25 pounds as compared to an average of 40 pounds for those on other graders tested. These low pressure tires provided easy riding for the operator and a minimum of abuse to the machine. Under normal conditions the soft tires tended to absorb unevenness, resulting in a smoother finish to the road bed.

It was the opinion of some engineers and operators that the low pressure tires have a higher resistance to sidewall cutting.

One of the disadvantages of the low pressure tires was a tendency of the machine to bounce several times after the blade passed over an obstruction, causing a series of ridges. Photograph No. 12 shows two series of ridges caused by two rocks imbedded in the surface. This difficulty, however, was not judged to be of a serious nature.

Fig. 12. Ridges caused by rock obstructions

VII. TANK CAPACITY

Comparative tank capacities are shown in Table XI.

TABLE XI

Fuel Tank Capacities

Warco	Maximum Others	Minimum Others
53 gal	60 gal	45 gal

The 53 gallon capacity of the Warco was sufficient for eight hours of operation during the test, and was judged adequate for field operations.

VIII. REMOVAL OF WINDOWS, DOORS AND CAB

The cab of the Warco grader could be removed in the shop in approximately three hours. The work involved would be the removal of approximately 30 bolts, plus removal and replacement of lights.

The removal of windows and doors was similar to that of other units; i.e., either removal of hinge pins or hinge bolts, which would require approximately 15 to 20 minutes.

It would be possible to handle windows and doors in the field, but removal of cab itself, as with other graders, would best be done in a shop having facilities for handling with safety.

IX. LIGHTS

Intensity of lights, measured with a Weston meter at a distance of three feet from the light source, was approximately 700 Weston units. The lights could be adjusted in a vertical plane and were considered as adequate for illumination of blade and roadway in night operation. Lights were located on the front of the cab 5'1½" above ground level, and were so positioned that adequate forward illumination for highway travel was obtained. Protection for the light lens was not provided. Two tail lights were mounted on top of the engine radiator. No stop light nor light to illuminate area to the rear of the unit was provided.

X. ENGINE STARTING

Average temperature for four observed starts was 60°F. The engine started on gasoline within 12 seconds and was run on gasoline for an average time of approximately 53 seconds before being cut over to diesel operation.

Starting was considered as good, since it compared favorably with the minimum average of 49 seconds and the maximum average of 133 seconds for other machines.

XI. OPERATION OF CONTROLS

No specific difficulties were encountered with the operation of the controls. Interference of shift lever with throttle as shown in Fig. 13 was noted. It is suggested that for ease of operation, the location of the throttle be changed.

Fig. 13. Throttle Shift Lever Interference

XII. TURNING RADIUS

(1) The turning radius was determined by the measurement of the minimum radius of the inside track. The distance between the inside and outside tracks was taken as the required road width for the turn. Results compared with other units are shown in Table XII.

TABLE XII

Turning Radius

	Warco	Maximum Others	Minimum Others
Turning Radius Right	28' 0"	27' 9"	21' 10"
" " Left	30' 6"	29' 3"	22' 9"
Average Road Width	11' 6"	13' 5½"	8' 1"

The turning radius of the Warco grader was larger than that of any other grader tested. Because of this, the road width required for turning was not as great as that required by other tandem graders.

It was the consensus of observers that these measurements are a direct reflection of the lack of wheel lean. It is further noted that there was considerable difference between the radius for the right and left turn. It is felt that some adjustment should be made to equalize the turning radius of the machine.

(2) Turn Around. The results of the turn around test are shown in Table XIII.

TABLE XIII

Turn Around

Backups Required on	Warco	Maximum Others	Minimum Others
35 Foot Road	3	3	2
30 Foot Road	5	7	3

In spite of larger turning radius, the operation of the Warco was satisfactory on all maneuverability tests.

XIII. BRAKE TEST

The hydraulic controlled Bendix Duo-Servo brakes utilized a standard hydraulic brake actuating system having a compensating type master cylinder and brake actuating cylinder at each tandem wheel. The parking brake lever actuates a brake band on the final drive pinion shaft of the transmission. Table XIV gives a comparison of the holding and stopping ability of the service and parking brakes of the Warco as compared with the maximum and minimum values found for other machines tested.

TABLE XIV

Brake Tests

	Warco	Other Machines Tested Maximum	Other Machines Tested Minimum
Service Brakes Uphill Hold	49%	49%	21%
" " Downhill "	49%	49%	34%
Park " Uphill "	32%	49%	27%
" " Downhill"	30%	49%	32%
Stopping Distance @ 18 mph.	25'6"	38'	15'

California State Vehicle Code stopping distance at 18 mph - 30'

The above table indicates that the Warco grader was equal to other machines in its ability to stop and hold on steep grades. However, it was necessary to adjust the parking brakes in order to hold the machine on slopes above 20%. The adjustment made was in the exterior linkage and was easily accomplished.

The service brakes were second best of tandem machines tested, and well within the limits considered safe for highway travel.

Photograph, Figure 14, shows an unprotected section of hydraulic brake line tubing across the tandem housing.

Fig. 14. Damaged Brakeline Tubing

The lines on both sides of the machine were damaged as shown. One line was damaged before machine had been removed from the flat car on which it was shipped to Arcadia. The other was damaged by being stepped on by the operator while servicing machine. It is felt that protection similar to that given the lines along the length of the tandem is desirable at this point.

XIV. WALKING TEST

1. The highway walking test was divided into two sections. The first covered travel over asphalt paved highway with grades up to two percent. The second section covered travel over dirt highway with grades up to eight percent.

2. The truck trail walking test was divided into uphill and downhill sections. Grades varied from fourteen percent uphill to ten percent downhill.

Table XV gives comparative speed data in miles per hour for each section of the highway and truck trail runs, as well as the overall speed in mph for each distance.

TABLE XV

Travel Speed (mph)

Route	Distance	Warco	Other Graders Tested	
			Maximum	Minimum
Paved Highway	4.2 mi.	21.60	24.60	15.80
Dirt Highway	1.9 mi.	15.20	17.54	12.35
Total Highway	6.1 mi.	19.05	19.94	14.50
Uphill Truck Trail	1.35 mi.	6.57	6.56	4.49
Downhill " "	2.3 mi.	10.26	16.24	9.13
Total Truck Trail	3.65 mi.	8.49	9.98	7.70

In the above walking test, the Warco was not the fastest but was above the average for the other machines tested. No difficulty with shifting or steering was encountered during these runs.

A third unscheduled test of the roadability of the Warco grader was made in the ferrying of the machine from Arcadia to the San Bernardino test site. The time required for a 45 mile heavily travelled highway stretch of this run in normal traffic was two hours for an average speed of 22.5 mph.

XV. BREAKDOWNS

In terms of breakdowns that rendered the machine inoperable, there were two breaks of the stud ball that connects the pitman arm to the Garrison steering booster control valve. Photograph, Figure 15, shows the nature of the break.

Fig. 15. Stud Ball Failure

The breakdown pictured, occurred twice during the ditching operation when the wheels were leaned to the left and sharply turned left. If, in this setting, the machine was in such position that the left wheel was at its lowest point as controlled by the stop on the front of the machine, sufficient bind was put on the Garrison cylinder to break the stud ball. Redesign of this assembly connection would eliminate this source of difficulty.

Other breaks in the equipment were at the saddle safety stop, as shown in Figure 16.

These stops were to prevent damage to saddle casting and ram assembly, and failure was due to poor welding. Three of the stops were welded by field personnel, and gave no further trouble.

Fig. 16. Saddle Stop Failure

XVI. FINAL CHECK

On completion of the test, the machine was returned to Arcadia for final check. A thorough check of the entire machine was made by shop mechanics, and no sources of major failure were evident.

At only one point did there appear any chafing of hydraulic hose. This was one of the hoses running from the head frame to the circle turning motor, and was chafing against the drawbar of the grader.

Wear on circle teeth was noted, but this was caused by circle being adjusted improperly during the grading test.

Several points of discussion arose regarding the overall design as it affects the operation of the machine for Forest Service truck trails. Some questions arose as to the ability of parts of the machine to withstand the loads of normal operations. Figure 17 shows a photograph of the saddle casting and lift arm assembly taken from the right hand side of the machine. Figure 18 shows a photograph of the forward end of the machine taken from the left side.

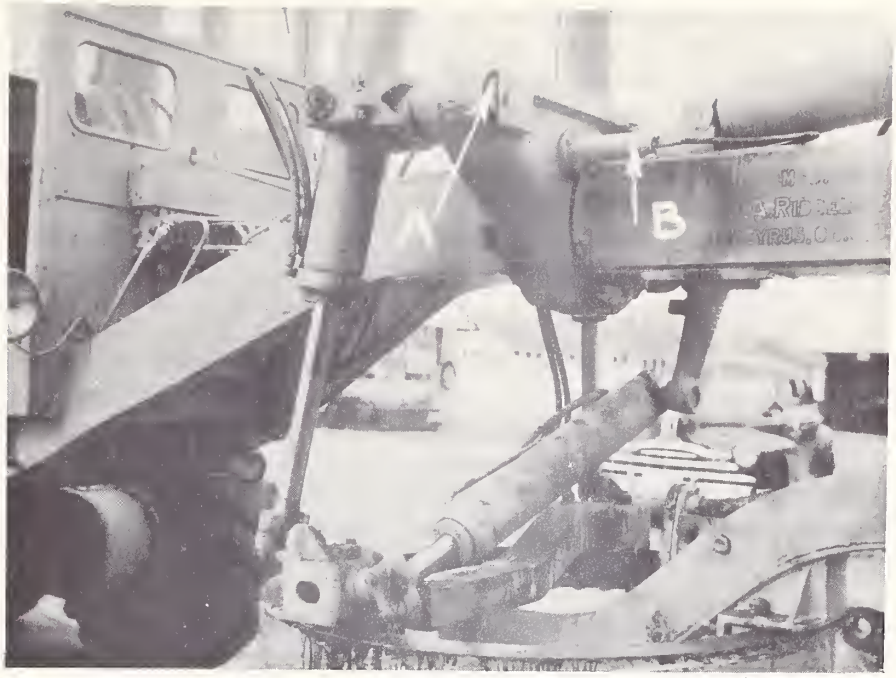


Fig. 17. Saddle Assembly

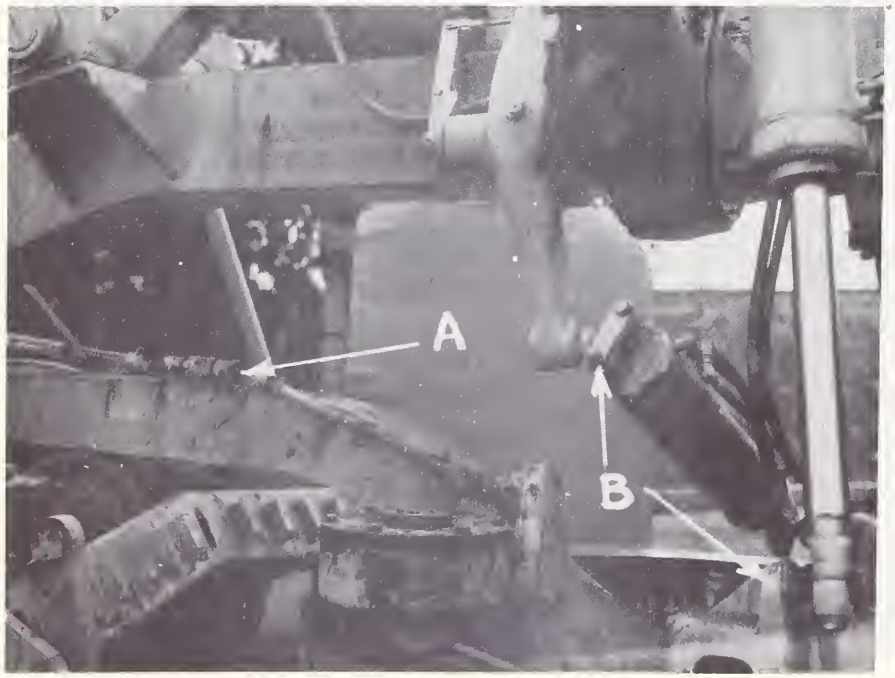


Fig. 18. Left Front View

In Fig. 17 arrow A points to the lift arm pivot bearing of the saddle casting. Looseness of this bearing, particularly on the right side of the machine, was noticeable. Since no means of adjustment was provided, the adequacy of this bearing was questioned.

Arrow B points to the saddle latch. All through the operations it was very difficult to disengage this latch. The taper of the latch pin is not sufficient to insure a tight fit in the index groove, and movement of the saddle affected the blade stability, particularly during fine grading operations.

Arrow A, in Fig. 18, shows connecting linkage from circle drive motor to the gear reduction box of the circle assembly. Wear in universal joints was considered as above normal. It was recommended that the hydraulic motor be moved to a mounting spot on the drawbar so as to eliminate these universals and support bearings. Arrows B indicate a point of interference of the crossarm of the drawbar and the drag link cylinder when in the lefthand high angle bank sloping position.

Fig. 19 is a photograph of the support brackets of the moldboard. Cracks in welding in both brackets, as indicated by the chalked line, show where the failure occurred. Heavier welding for this section of the blade support was done by the Forest Service shop, and is recommended for consideration by the manufacturer.

Fig. 19. Moldboard Support

In Fig. 20, arrow A points to the location of the latch meant to hold the cab door open during operation. These ~~were~~ not sufficiently strong and should be replaced with a more suitable type.

Arrow B shows the approximate point at which a grab iron for use of operator in getting into cab should be installed.

Fig. 20. Cab Side View

DISCUSSION OF RESULTS

FIELD TESTS

I. IN CURVE

In Figure 4 is depicted a typical condition often encountered in forest road maintenance. Here, a machine with a short turning radius that would travel the curve with a minimum of road width is required. Operation under the condition depicted was difficult for any of the tandem graders. Lacking backup room, the first turn into the wash was critical. The track width required for the Warco after being maneuvered to make the entry was 20' 1¼". This was in excess of road width requirements for all of the other tandem machines tested. As previously mentioned, a possible explanation lies in the low angle of wheel lean.

II. GRADING OF DIPS

The high lift and low point below ground level to which blade could be maneuvered, allowed for complete freedom of operation and satisfactory performance in most cases. Difficulties when noted were in areas where narrow road widths and turning radius were such as to require low travel speeds. Low gear speed was not sufficient in all instances to permit the various blade shifts required for dip operation without causing ridges.

Figure 21 is a photograph of the dip before grading operation. The following Figure 22 shows the same area after grading of the dip was completed.

Fig. 21. Dip Before Grading

Fig. 22. Dip - After Grading

III. DITCHING

The site of this ditching operation, Figure 23, was in the same area as that worked on by other units. Adjacent strips immediately to the right and left were worked on by other machines. Time required for the Warco to complete the ditch was average compared to other graders tested. Table XVI compares elapsed time of the Warco grader to the maximum and minimum for other graders.

TABLE XVI

Ditching

	Warco	Other Acceptable Machines Tested: Maximum	Minimum
Time to Construct Ditch	10 hr., 2½ min.	10 hr., 22 min.	8 hr., 20 min

Figures 24 and 25 show the ditching site during and after operation.

Fig. 23. Ditching Site Before Operation

Fig. 24. Warco Ditching Operation

Fig. 25. Warco - Completed Ditch

It is recognized that this ditching test was most severe and beyond the normal operations encountered or anticipated. It was in effect an accelerated aging test to determine the ability of the grader to withstand severe abuse. It was the consensus of the observers that the finished ditching and bank sloping job was very good.

Trouble was experienced with the Warco grader in attempting to slope the shoulder to the required angle of 3/4 to 1. Manual shifting of moldboard on support arms eliminated difficulty but served to point up the fact that an attempt to do the job from center position was preferable to the operator rather than the manual work necessary to shift the blade on the moldboard support arms. It was in this operation that operators were definite in their recommendations that power moldboard shift was desirable. Basis of their decision was that manual shift from center to bank slope and back to center required approximately one-half hour for a bank sloping operation that required only nine minutes to perform.

IV. SCARIFYING

The work of scarifying was satisfactory and comparable to the operation of other machines tested. However, tooth base stock of the Warco was thought to be softer than that of other machines tested, since bending during tests was experienced. Photograph, Figure 26, shows condition of scarifier teeth after 20 minutes of operation at the ditching site.

Fig. 26. Bent Scarifier Teeth

VII. UPHILL GRADING

In the uphill grading test, operator's complaint was because of inability to shift blade under load. It was necessary to raise blade to spill load, with a resultant corrugated effect in the road bed. The material of the road bed was decomposed granite and grades averaged 15%. Table XVII gives the overall time required for the Warco as compared with that of other graders operated over the same course.

TABLE XVII

Uphill Grading

	Warco	Other Graders Tested: Maximum	Other Graders Tested: Minimum
Time to do Uphill Grading (500')	3 min., 40 sec.	4 min.	2 min., 50 sec.

It was noted that during the uphill grading test, when blade encountered a heavy load, tires flexed to a point that it was felt bouncing was reflected in ridges left by the blade in the road bed. This was somewhat controversial and could not be definitely established. Appraisal of the Warco on the uphill grading operation resulted in an accumulation of negative conditions which gave an overall fair, but acceptable, rating for the unit.

VIII. ROAD MAINTENANCE

The two mile maintenance run was the last of the field tests performed, and combined all operations included in the previous tests with the exception of bank sloping. Due to inclement weather, the first run on Lytle Creek Ridge Road, which was used in previous tests, was discounted, and a second test over the Barton Flats truck trail of the Angeles Forest was run. In the opinion of operators, the second run should be considered as approximately 25% more difficult than the original course due to narrower road widths and extremely hard outcropping rock.

As with all other graders, the two mile field test of road maintenance in effect did little more than verify the findings of the previous specialized tests. It did, however, serve the purpose of indicating overall productivity in terms which could be compared to normal field performances and with which field personnel were familiar. In this respect, the value of the two mile test can be considered as one of the most important of the tests performed.

The second test course selected for the Warco grader was two miles long, and 18 interceptor drainage dips, 2 minimum curves (less than 35' radius), grades up to 11%, and had 26 stretches with road width of less than 11 ft. Road material was decomposed granite with residual rocks of granodiorite.

Three passes were made for an average operating speed of 1.75 miles per hour, or an elapsed time for the complete job of 3 hrs., 26 mins. Averaged speeds of other graders ranged from 1.41 mph to 1.91 mph.

This test conclusively showed that the Warco, with a low governed speed of 2.6 mph, was too fast for normal operation on rocky narrow roads. The low speed of the Warco was higher than that of all other tandems in standard production. Operators felt that a lower speed of approximately 1.8 mph at full throttle in low gear would be more suitable for normal Forest Service truck trail maintenance.

Many photographs were taken before and after the two mile grading test in an effort to record and preserve a basis of comparing operation of the Warco with other units. Photographs, Figure 28 through Figure 33, present before and after shots of the truck trail over which the Warco operated.

In summarizing the two mile maintenance test it was the considered opinion of field men and observers that the Warco Grader had done a very good job. In view of the test road selected, narrow width, type of road bed and amount of sluff material to be removed, the final appearance of the finished job was judged as being equal or superior to the best of the results obtained from the machines operated in the 1950 tests.

Difficulties previously noted were reflected in the results of this run. Corrugated effects on the finished road, low speed troubles, and the others previously mentioned, while present to a degree were considered as not having seriously effected the appraisal.

In view of results accomplished, the recent production of this model, and the minor nature of needed correction, observers were unanimous in their approval of the Warco 4D 100.

Fig. 28. Road Maintenance - Before

Fig. 29. Road Maintenance - After

Fig. 30. Sluff Prior to Grading

Fig. 31. Same Area After Grading

Fig. 32. Typical Road Section Before Grading

Fig. 33. Same Section After Grading

CONCLUSIONS

Conclusions formulated and expressed are the result of experience with and test of the Warco 4D 100, Serial No. 4D-105923 submitted by the W. A. Riddell Corporation of Bucyrus, Ohio.

FLATLAND TESTS

1. Weight distribution for the test machine conforms to general design practice for equivalent machines, and was considered adequate.

2. Weight horsepower ratio was above the average of the other tandem machines tested, and was considered an advantage.

3. Overall dimensions, although slightly higher than those of other machines, apparently had no detrimental effect on operation when compared with other acceptable tandems.

4. The number of forward and reverse speeds was considered adequate.

5. Engine performance was adequate for normal field operation.

6. Flexibility in maneuvering blade was superior to that of any unit previously tested.

7. The majority of blade positions could be obtained by cab controls only. The addition of the available power ram shift of moldboard would make the Warco completely cab controlled for all operations.

8. Based on performance of other acceptable machines, increased angle of wheel lean was desirable.

9. Wheel visibility and road visibility were classed as very good. New operators experience difficulty in judging blade lift, due to acute angle of observation from high cab.

10. Average overall ground clearance was adequate.

11. Service maintenance was in general less than the average requirements of other units.

12. Tires and rims were adequate.

13. The tank capacity, although the smallest of all acceptable graders tested, was sufficient for a full day of normal operation.

14. Work involved in the removal of cab, windows, doors, etc., was comparable to that of other machines.

15. Lights were adequate, although it was felt that they should be mounted on the front panel of the grader so as not to complicate cab removal.

16. Operation of hydraulic hand controls was satisfactory. It was felt by operators that the manufacturers of hydraulic machines should standardize on the location of control valves with respect to each other.

17. Engine and transmission controls operated satisfactorily.

18. Relocation of hand throttle was considered necessary.

19. Turning radius, although slightly higher than that of other tandems tested, did not adversely affect field operations.

20. Service and parking brakes were adequate.

21. Hydraulic system operated satisfactorily. It was the conclusion of operators and observers that more blade torque was needed.

22. Travel speeds were equal to the fastest of the graders. Speed in lowest gear at full throttle was not considered low enough for normal low speed maintenance on Forest Service roads.

23. Cab needs improvement. Better seat cushion fastening, grab irons and better latches to hold doors open are the more important needs.

FIELD TESTS

1. Performance of the Warco on the incurve test compared favorably with other tandems.

2. Ability to construct and maintain dips was considered adequate.

3. Performance during the ditching operation was satisfactory. The heavy work accomplished by the Warco indicated an inherent ability to stand up under prolonged and rugged field operation.

4. The finished job of scarifying was acceptable. Scarifier teeth bent sideways and should be made of larger cross section or be built of a better grade of steel.

5. The Warco was able to bank slope to a high standard and equal to the best of the other machines tested.

6. In the hill climb, performance of the Warco was adequate.

7. The uphill grading test showed that the Warco was capable of doing satisfactory work on the grades encountered on mountain truck trails.

8. Daily maintenance and lubrication requirements were considered average.

9. The overall job on the two mile maintenance section was appraised by road engineers as satisfactory.

10. The Warco 4D 100 grader was judged to be equal in performance to the best of the other tandem graders tested and, with the exception of the minor items noted in this report, meets specification requirements and is considered an acceptable machine for Forest Service operations.

A P P E N D I X

RATING TABLE

As a check on the results of the motor grader test, a rating table was prepared to include several of the more common items generally considered when discussing patrol graders. The theory in the preparation of this table, if it can be so called, is based somewhat on the laws of random sampling.

Eight men - three engineers, one ranger, one mechanical draftsman-designer, two Depot Superintendents, and one Regional Office staff man - completed a rating table for the five graders, to include twenty-three items normally associated with equipment of this type. The items were listed only as headings with no detail to cover definition. Instructions for preparation requested that the rater draw his own conclusions as to the inference in the item, and rate accordingly. Rating was to be made by indicating the best as one, second best - two, etc., with machines of equal ability being rated by the same digit.

It was also recognized that all 23 of the rating items did not bear the same weights as to importance. Accordingly, each person preparing the questionnaire was requested to evaluate the relative importance of each and establish some weighting scale to cover.

A typical final form is shown with the items weighted, but without the ratings for the individual graders.

GRADER SCORING SHEET

	Weight Rating	A-C	Cat.	Rome	A-W	Adams
Blade Opr.	6					
Engine Starting	3					
Transmission Shift	5					
Opr. of Controls	6					
Breakdowns	4					
Availability of Parts	4					
Maint. Nec. to Opr.	1					
Walking Speeds	3					
Maneuverability of Machine	5					
Safety - Brakes	7					
Visibility	5					
Controls Shift	6					
Opr. Fatigue	5					
Opr. Training Necessary	1					
Dip Const. & Maint.	8					
Ditching	5					
Drifting	3					
Bank Sloping	2					
Scarifying	5					
Move Windrow	6					
Remove Slides	6					
Road Maint.	8					
Fine Grading	2					

AAA DETONATOR BRAKE TESTER

The electrically operated detonator brake tester, shown in photograph, Fig. A, is used to measure the effectiveness of equipment brakes. Mounted on the machine being tested, it is operated by two switches - the first controlled by an observer and the second mounted on the brake pedal.

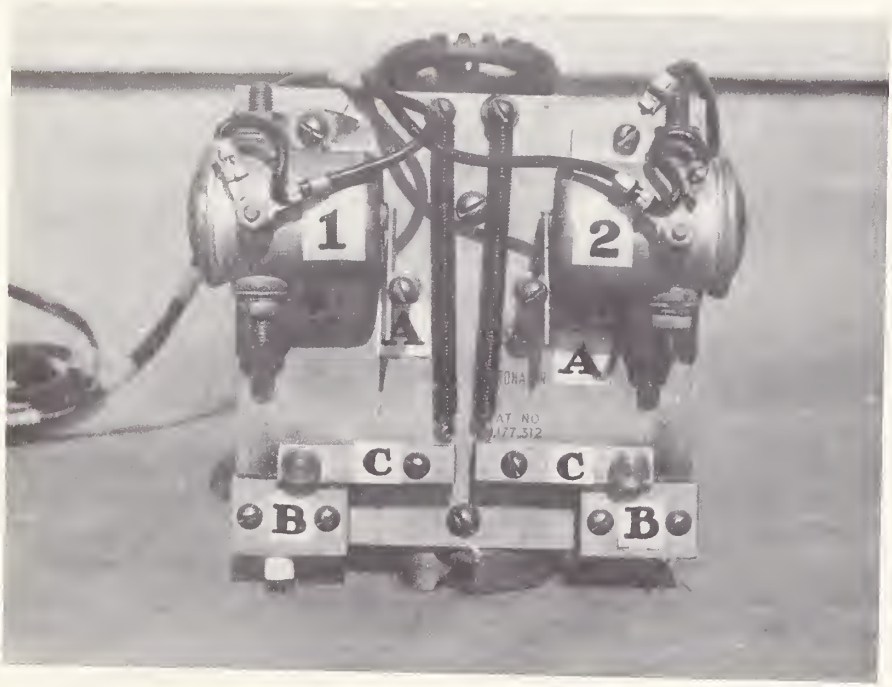


Fig. A. AAA Detonator Brake Tester

With the machine moving at the predetermined test speed, the observer operates the switch that releases solenoid 1 and allows its spring loaded hammer C to fire a blank cartridge in the block B. The force of the explosion expels chalk in the block and makes a mark on the pavement. On hearing the shot, the operator hits the brakes, causing the brake switch to release Solenoid 2, which fires a second piece of chalk to the pavement. When the machine comes to a complete stop a third chalk mark is made on the pavement directly under the detonator firing blocks.

The distance between the first and second shalk marks is measured and, since the speed of travel is known, can be converted into operator reaction time. The measurement between the second and third marks is the distance required to bring the vehicle to a stop at the given speed.

A complete description of the operation and use of this brake tester is available at the Arcadia Equipment Development Center, 701 N. Santa Anita Ave., Arcadia, California.